INTERPLANETARY DUST PARTICLES AND SOLAR RADIATION

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Abstract. The problem of the action of the solar radiation on the motion of interplanetary dust particle is discussed. Differences between the action of electromagnetic solar radiation and that of the solar wind are explained not only from the point of view of the physical nature of these phenomena but also from the point of view of dust particle's orbital evolution. As for the electromagnetic solar radiation, general equation of motion for the particle is written and the most important consequences are: (i) the process of inspiralling toward the Sun is not the only possible motion – even spiralling from the Sun is also possible, and, (ii) the orbital plane of the particle (its inclination) may change in time. As for the solar wind, the effect corresponding to the fact that solar wind particles spread out from the Sun in nonradial direction causes that the process of inspiralling toward the Sun is in more than 50% less effective than for radial spread out; in the region of the asteroid belt (long period orbits) the process of inspiralling is changed into offspiralling. Also shift in the perihelion of dust particle's orbit exists.

1. Introduction

Orbital motion of small interplanetary dust particles (IDPs) is controlled not only by gravitational forces (between IDP and Sun or any planet). Also nongravitational forces play an important role, mainly as for the long-term orbital evolution. The solar radiation seems to be the most important nongravitational effect for particles in radii $1 \mu m - 1$ cm (approximately).

Solar radiation consists of the two parts: electromagnetic and corpuscular. The action of the electromagnetic solar radiation on the motion of dust particle was investigated by Robertson (1937) for perfectly absorbing sphere. Everybody knows this dynamical effect as the Poynting–Robertson effect (P–R effect). Corpuscular solar radiation is generally well-known as the solar wind. Its correct action on IDPs was presented by Dohnanyi (1978). We want to discuss physics of these two different effects and point out to analogies and differences between them also from the point of view of their importance in long-term orbital evolution of IDPs.

2. Electromagnetic Solar Radiation

In the local inertial reference frame of the moving particle, we can write

$$p'_i = \frac{1}{c} A_{e\text{ff}} S' \hat{S}'_i,$$

(1)

where \( \mathbf{p}' \) is momentum of radiation (photons) crossing an area \( A_{\text{eff}} \) per unit time; \( S' \) is flux of the radiation which spreads in the direction defined by unit vector \( \hat{S}' \). After interaction between this incident radiation and dust particle, we can write for the resulting 'outgoing' radiation

\[
p' = \frac{1}{c} A_{\text{eff}} S'(z\hat{S}' + m\hat{e}_T + n\hat{e}_N),
\]

(unit vectors present on the right-hand-side are mutually orthogonal). No condition is put on \( z, m \) and \( n \) in our general considerations (one must bear in mind that in reality effective cross-section for the incident radiation is different from that used in outgoing radiation). Equation (2) is a generalization of a special case treated in Kláčka (1993d), which points out that nonradial terms - corresponding to \( m, n \)-terms - may be nonzero even for rapidly rotating particles. Equation of motion for the particle is then

\[
\frac{dp'}{dt'} = \frac{1}{c} A_{\text{eff}} S' \{(1 - z)\hat{S}' - m\hat{e}_T - n\hat{e}_N\}.
\]

Let us describe the motion of the particle in the reference frame of the Sun. These relations hold (particle moves with the speed \( v \))

\[
\hat{S}' = (1 + v \cdot \hat{S}_i/c)\hat{S}_i - v/c,
\]

(see Equation (18) in Kláčka, 1992a, Equation (19) in Kláčka, 1993b; the direction of the incident (solar) radiation is characterized by a unit vector \( \hat{S}_i \) in the reference frame of the Sun),

\[
\hat{e}_T' = \hat{e}_T + \frac{v \cdot \hat{e}_T}{c} \hat{S}_i, \quad \hat{e}_N' = \hat{e}_N,
\]

\( \hat{e}_T \) is unit vector transverse to the radial vector \( \hat{S}_i \) in the tangential plane to the trajectory (positive in the direction of motion) of the particle, \( \hat{e}_N = \hat{e}_R \times \hat{e}_T \), (see Equation (5) in Kláčka, 1993d; \( \hat{e}_R = \hat{S}_i \)),

\[
S' = S(1 - 2v \cdot \hat{S}_i/c),
\]

(see, e.g., also Kláčka, 1993c for discussion). On the basis of Equations (3)–(6), using also Lorentz transformations (\( dE'/dt' = 0 \)), we can write (\( m_p \) is particle's mass)

\[
\frac{dv}{dt} = A_{\text{eff}} \frac{S}{m_p c} \{(1 - z)[(1 - v \cdot \hat{S}_i/c)\hat{S}_i - v/c] - (1 - 2v \cdot \hat{S}_i/c)(m\hat{e}_T + n\hat{e}_N) - (m(v \cdot \hat{e}_T/c)\hat{S}_i)\}.
\]

This is the complete form of the equation of motion for dust particle (of general shape) moving under the action of the electromagnetic field. The first part on the